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Diamonds at the nanoscale: A sparkling future for dentistry

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Abstract
Nanotechnology revolutionizes modern dentistry. Among recent advances in the field, Nanodiamonds, carbon-based nanoparticles with a crystalline sp^3-hybridized diamond core and versatile surface functionalization, have emerged as promising biomaterials. Their unique physicochemical properties like extreme hardness, large surface area, chemical stability and excellent biocompatibility facilitate diverse applications across restorative dentistry, endodontics as well as other branches like prosthodontics and periodontics including implantology. These are fabricated by various methods such as detonation synthesis, chemical vapor deposition, laser ablation, and hydrothermal or electrochemical approaches that allow scalable production with customized surface chemistry, while post-synthesis functionalization enhances therapeutic performance, stability and solubility. Various In*vitro* and preclinical studies demonstrate that nanodiamond incorporation enhances composite durability, adhesive bond strength, release of fluoride, and biofilm disruption, promote osteogenesis, angiogenesis, and osseointegration by forming scaffolds. Furthermore, nanodiamond-based carriers enable controlled drug release and serve as imaging probes, expanding their biomedical relevance. Despite these advantages, challenges include variability in synthesis protocols, limited long-term safety data, and regulatory hurdles that limit translating into clinical practice. Future directions should focus on standardized functionalization, rigorous *in vivo* evaluation, and integration into regenerative and minimally invasive dental therapies. Overall, nanodiamonds represent a versatile biomaterial with significant potential to enhance dental materials, improve treatment outcomes and contribute to biologically driven innovations in modern dentistry.

Keywords: Nanodiamonds, dentistry, biocompatible materials, drug delivery systems, tissue regeneration

Introduction
Nanotechnology has transformed dental materials by enabling significant improvements in their mechanical, biological, and therapeutic performance. Among carbon-based nanomaterials, nanodiamonds have emerged as particularly promising owing to their sp^3-hybridized diamond core, large specific surface area, excellent biocompatibility, and versatile surface functionalization. These unique properties have facilitated their application in restorative dentistry, endodontics, regenerative therapies, and a wide range of biomedical fields. This review critically evaluates the current evidence on the use of nanodiamonds in dentistry, integrating findings from laboratory investigations, translational biomedical research, and emerging clinical perspectives to highlight their potential, limitations, and future directions [1, 2].

Properties of Nanodiamonds
- Nanodiamonds are carbon nanoparticles with a truncated octahedral architecture that are typically about 2-8nm in diameter and consist of a crystalline sp^3-hybridized diamond core surrounded by a thin amorphous (sp^2-rich) carbon shell [3].

- **Surface Features**: Exhibit hydrophilicity, intrinsic fluorescence, and ease of surface functionalization with surface functional groups like -carboxyl, -amino, -hydroxyl groups to prevent non-specific protein interactions and improve the solubility [4].

- **Advantages**: They not only exhibit various superior properties of diamond such as chemical stability, extreme hardness, but also have advantages like small size, large surface area and high adsorption capacity. They also possess capacity for sustained drug release, mechanical reinforcement and antibacterial activity [5]. Fluorescent nanodiamonds enable safe, durable imaging [6].

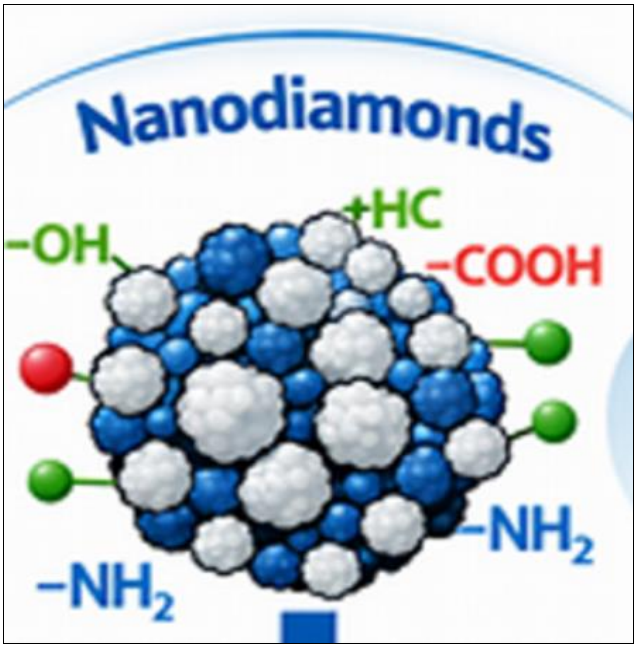


Fig 1:

Fabrication Methods

Nanodiamonds can be obtained through various methods, each offering distinct advantages in terms of purity, scalability and surface properties:

Table 1:

Fabrication Method	Key Features	Dental Relevance
Detonation Synthesis [1, 3]	Large-scale, cost-effective; crystalline diamond core with amorphous carbon shell	Widely used for nanodiamond fille1rs in composites, adhesives, and endodontic sealers
Chemical Vapor Deposition [7]	Produces high-purity polycrystalline diamond films; precise control of morphology	Implant coatings and prosthetic devices; enhances hardness, wear resistance, osseointegration
Laser Ablation [8]	Controlled particle size and surface chemistry; optical clarity and fluorescence	Bioimaging applications and functional dental materials requiring fluorescence
Hydrothermal Synthesis [8]	High-pressure, high-temperature aqueous reactions; tuneable surface groups	Drug delivery carriers and regenerative scaffolds for endodontics and tissue repair
Electrochemical Methods [8]	Fine control over particle size and functionalization	Targeted drug delivery systems and bioactive dental composites
Post-Synthesis Functionalization [1]	Surface modification (–COOH, –OH, $–NH_2$) improves solubility and biocompatibility	Enhances performance in composites, adhesives, and endodontic drug delivery systems

- **Detonation Synthesis (Primary Method):** The most commonly utilized and cost-effective method is the detonation method where there is controlled explosion of carbon-rich explosives under hypoxic conditions. Nanodiamonds with an amorphous carbon shell and crystalline core is formed. Large-scale production is possible, making this method particularly for biomedical and dental applications. But post-synthesis purification like acid treatment and annealing is essential to remove graphitic impurities and improve biocompatibility [3].

- **Chemical Vapor Deposition:** (CVD) produces high-purity polycrystalline diamond films, which are especially applicable in coating dental implants and prosthetic appliances. Thus, there is control over thickness of film and surface morphology, improving hardness, resistance to wear, and osseointegration [7].

- **Laser Ablation:** Here, high-power laser pulses are used to ablate graphite or diamond targets, producing nanodiamonds with controlled size distribution and tailored surface chemistry. This technique is particularly advantageous for applications requiring optical clarity and fluorescence, such as bioimaging [8].

- **Hydrothermal and Electrochemical Methods:** here high-pressure, high-temperature reactions take place in aqueous media, yielding nanodiamonds with tuneable surface groups. Electrochemical approaches enable precise control over particle size and functionalization, making them appropriate for drug delivery systems and to be used as scaffold in regenerative dentistry [8].

- **Post-Synthesis Functionalization:** Surface modification (carboxylation, hydroxylation, amination) is crucial to improve solubility, avoid aggregation, and enable conjugation with biomolecules. Taymour *et al*. (2024) emphasize that functionalization protocols directly influence biocompatibility and therapeutic performance, particularly in restorative materials like dental composites, adhesives, and endodontic applications [1].

Biocompatibility

- ***In vitro*:** Nanodiamonds demonstrate minimal cytotoxicity and excellent cellular compatibility due to their pure carbon core, outperforming carbon nanotubes (CNTs) and carbon black in biocompatibility tests [2, 5].

- **Surface Functionalization:** Carboxylation and polymer coatings improve the biocompatibility, colloidal stability, and compatibility of nanodiamonds with biological systems [5].

- ***In vivo* Nanodiamond Hydrogels:** Nanodiamond-based hydrogels provide sustained vascular endothelial growth factor (VEGF) release while exhibiting favorable biodegradability, making them promising platforms for tissue engineering and regenerative applications [9].

Biomedical Applications

- **Drug delivery:** Nanodiamond-based carriers enable controlled and sustained release of antibiotics, anticancer agents, and therapeutic biomolecules, improving drug stability, bioavailability, and targeted delivery due to nanomediated endothelial leakiness at targeted disease sites [2, 6].

- **Bioimaging:** Fluorescent nanodiamonds serve as stable, photostable, and biocompatible imaging probes, enabling long-term, non-toxic cellular and tissue imaging [6].

- **Tissue engineering:** Nanodiamond-based scaffolds promote osteogenesis and angiogenesis, enhancing tissue regeneration and supporting bone repair [11].

- **Implant Surface Modification:** Nanodiamond coatings enhance osseointegration while reducing bacterial adhesion and colonization, thereby improving

the biological performance of dental and orthopedic implants [7].

Dental Applications

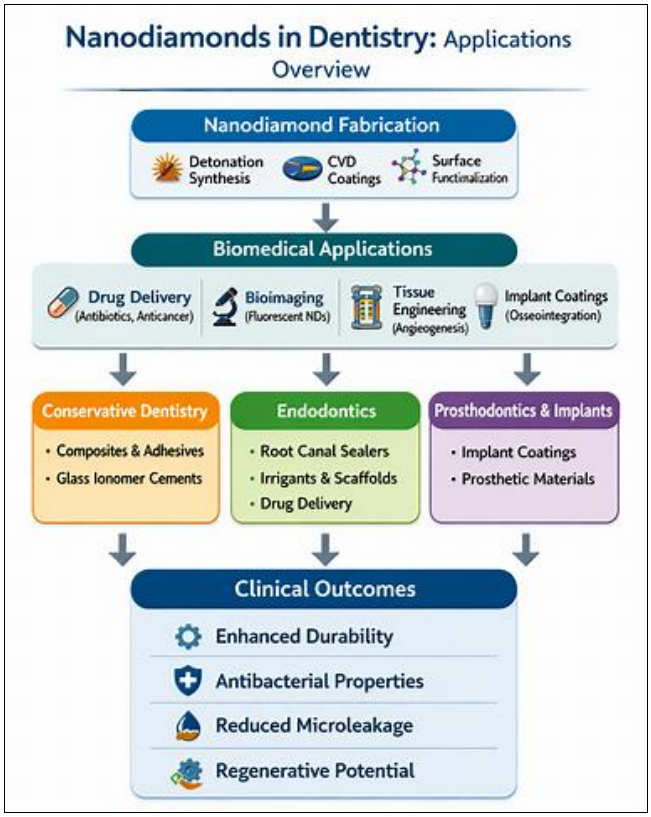


Fig 2:

Conservative Dentistry

- **Restorative Composites:** Nanodiamond fillers enhance resin-based composites by acting as nanoscale reinforcements. Their extreme hardness and truncated octahedral crystalline structure provide superior resistance to wear and fracture. The large surface area of NDs enables strong interfacial bonding with the polymer matrix, reducing microcrack initiation and propagation. This results in composites with improved mechanical strength, longevity, and resistance to degradation under masticatory forces [1].

- **Bonding Agents:** In adhesive systems, nanodiamonds improve dentin and enamel bond strength by increasing surface energy and wettability. Their functional groups (–COOH, –OH, –NH_2) form hydrogen bonds and covalent interactions with collagen fibrils in dentin, stabilizing the hybrid layer. This reduces nanoleakage and enzymatic degradation, thereby prolonging the durability of the adhesive interface [3].

- **Glass Ionomer Cements:** Nanodiamonds incorporated into glass ionomer cements act as reinforcing fillers that improve compressive strength and fracture toughness. Their surface chemistry facilitates fluoride ion exchange, enhancing remineralization of adjacent tooth structures. Additionally, their antibacterial activity reduces secondary caries risk, making ND-modified cements both mechanically stronger and therapeutically superior [5].

- **Sealants and Varnishes:** Nanodiamond-based sealants and varnishes provide remineralization potential by serving as nucleation sites for hydroxyapatite crystal growth. Their bioactive surfaces promote enamel repair and enhance caries prevention. The combination of mechanical reinforcement and bioactivity makes them promising adjuncts in preventive dentistry [1].

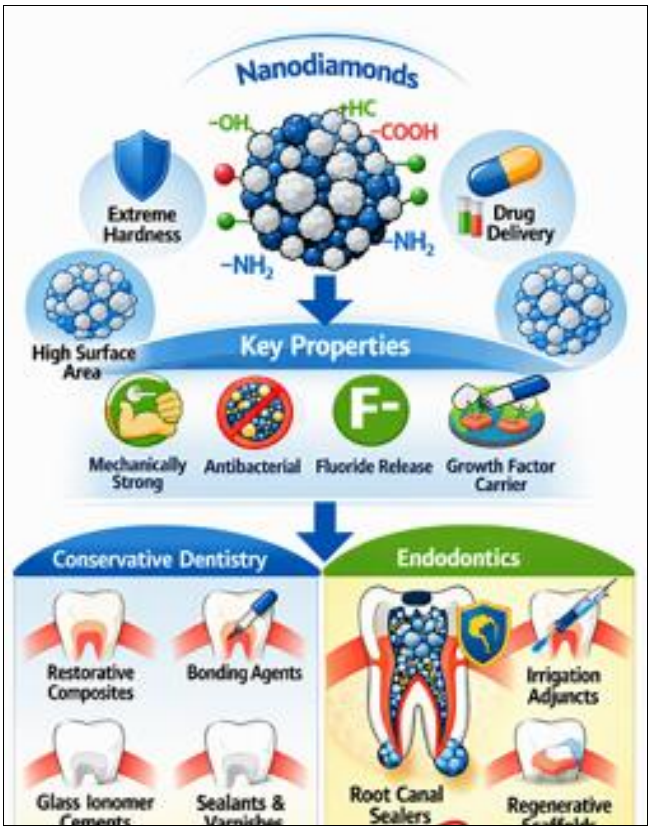


Fig 3:

Endodontics

- **Root Canal Sealers:** Nanodiamonds improve the sealing ability of root canal sealers by filling microvoids and enhancing dimensional stability. Their antibacterial properties arise from their ability to adsorb onto bacterial membranes, destabilize biofilms, and reduce microbial colonization. This dual sealing–antibacterial effect contributes to improved long-term treatment outcomes [10].

- **Irrigation Adjuncts:** Nanodiamond suspensions exhibit potent antibiofilm activity. Their nanoscale size allows penetration into dentinal tubules, where they adsorb onto bacterial cell walls and disrupt biofilm architecture. Compared to conventional irrigants like NaOCl or CHX, ND-based irrigants provide deeper disinfection and reduce biofilm persistence, thereby enhancing root canal asepsis [10].

- **Regenerative Endodontics:** Nanodiamond-incorporated scaffolds act as carriers for growth factors such as VEGF and BMP-2. Their large surface area and abundant functional groups enable efficient adsorption and controlled release of these biomolecules. Sustained release promotes angiogenesis, odontogenic differentiation, and pulp–dentin complex regeneration,

making NDs valuable in regenerative endodontic protocols [11].

- **Intracanal Drug Delivery:** Nanodiamonds serve as carriers for antibiotics like amoxicillin. Their porous surfaces and functional groups allow efficient adsorption of drug molecules, followed by controlled and sustained release within the root canal system. This maintains therapeutic concentrations over extended periods, enhances antibacterial efficacy against *Enterococcus faecalis*, and reduces reinfection risk. Importantly, NDs preserve biocompatibility, ensuring that prolonged drug release does not harm periapical tissues. ND–antibiotic conjugates therefore represent a promising adjunct to conventional intracanal medicaments, particularly for managing persistent and refractory infections [2, 5, 6, 10].

Prosthodontics and Implantology

Prosthodontics: Nanodiamond reinforcement in polymethyl methacrylate (PMMA) improves flexural strength, fracture toughness, and wear resistance. Their high surface area ensures strong bonding with the resin matrix, reducing crack propagation and microbial adhesion while maintaining esthetics [12].

Implantology: Nanodiamond coatings on titanium implants enhance osseointegration, corrosion resistance, and antibacterial performance. The sp^3-hybridized diamond structure promotes osteoblast adhesion and reduces biofilm formation, while functionalized surfaces enable localized release of growth factors or antibiotics for improved healing [7,11].

Periodontics

Nanodiamonds are emerging as promising adjuncts in periodontal therapy. Their antibacterial properties help reduce biofilm formation and pathogenic colonization on root surfaces, supporting periodontal pocket disinfection. Functionalized nanodiamond carriers can deliver antibiotics or anti-inflammatory agents directly into periodontal sites, ensuring controlled and sustained release for improved therapeutic outcomes. In regenerative periodontics, ND-incorporated scaffolds enhance osteogenesis and angiogenesis, promoting alveolar bone regeneration and periodontal ligament repair. Their biocompatibility and ability to adsorb growth factors make them valuable in guided tissue regeneration protocols [2, 5, 11].

Table no.2 shows comparative evaluation of Nanodiamonds and Conventional Additives in Dentistry

Table 2: Comparative Table: Nanodiamonds vs. Conventional Additives in Dentistry

	Conventional Materials	Nanodiamond Advantages	Key References
Restorative Composites	Silica, zirconia fillers	↑ Mechanical strength, ↑ wear resistance, improved longevity	Taymour *et al*. 2024 (doi:10.1002/slct.202401328)
Bonding Agents	Resin monomers	↑ Bond durability, ↑ surface energy, better dentin/enamel adhesion	Krueger 2009 (doi:10.1080/10408430902831987)
Glass Ionomer Cements	Aluminosilicate glass	↑ Compressive strength, ↑ fluoride release, antibacterial activity	Shenderova 2016 (doi:10.1002/jbm.a.36369)
Endodontic Sealers	Epoxy resin, calcium silicate	↑ Sealing ability, antibacterial properties, dimensional stability	Int Endod J 2024 (doi:10.1111/iej.14176)
Irrigation Adjuncts	NaOCl, CHX	ND suspensions reduce biofilm persistence, ↑ antimicrobial efficacy	Zhang *et al*. 2012 (doi:10.2147/IJN.S37348)
Regenerative Endodontics	Collagen scaffolds, PRF	ND hydrogels deliver VEGF/BMP-2, promote pulp-dentin regeneration	Zheng *et al*. 2017 (doi:10.1073/pnas.1711924114)
Implant Coatings	Titanium oxide, hydroxyapatite	↑ Osseointegration, ↓ bacterial colonization	Krueger & Lang 2015 (doi:10.1002/ppsc.201500027)

Limitations

- Limited long-term data are available regarding the biocompatibility, and potential toxicity of nanodiamonds, highlighting the need for comprehensive preclinical and clinical evaluation [9].
- Standardization Challenges Variability in synthesis, purification, and surface functionalization protocols can affect the physicochemical properties, reproducibility, and biological performance of nanodiamonds [3].
- The lack of standardized testing protocols across dental applications limits the comparability of findings and hinders the translation of nanodiamond-based technologies into clinical practice [5].
- Regulatory hurdles, including stringent safety, quality, and efficacy requirements, remain significant barriers to the clinical translation and commercialization of nanodiamond-based dental technologies [6].

Future Directions

- **Standardization of Functionalization:** Development of standardized nanodiamond surface functionalization methods are essential to ensure reproducibility, consistent performance, and successful clinical translation [3].

- **Long-Term Safety Evaluation:** Well-designed long-term *in vivo* studies are needed to establish the safety, biocompatibility, biodistribution, and potential toxicity profiles of nanodiamonds before routine clinical use [9].

- **Clinical Integration:** Integration of nanodiamond-based materials into regenerative endodontic and conservative dentistry protocols holds promise for enhancing treatment outcomes and advancing minimally invasive, biologically driven therapies [10].

- **Multifunctional Biomaterials:** Exploration of nanodiamond hybrids with bioactive molecules offers opportunities to develop multifunctional dental materials with enhanced antimicrobial, regenerative, and therapeutic properties [11].

Conclusion

Nanodiamonds have emerged as one of the most promising

nanomaterials in modern dentistry due to their unique physicochemical properties, excellent biocompatibility, and versatile surface functionalization. Their potential applications extend across restorative dentistry, endodontics, regenerative therapies, and implantology, highlighting their ability to address a wide range of clinical challenges. Although current laboratory and preclinical findings are encouraging, further research is needed to establish their long-term safety, optimize standardized fabrication protocols, and validate their clinical effectiveness. With continued advances in translational research and well-designed clinical trials, nanodiamond-based materials have the potential to become an integral part of future conservative dentistry and endodontic practice.

References

1. Taymour N, Haque MA, Atia GAN, Mohamed SZ, Rokaya D, Bajunaid SM, *et al.* Nanodiamond: A promising carbon-based nanomaterial for therapeutic and regenerative dental applications. ChemistrySelect,2024:9(35):202401328. doi:10.1002/slct.202401328.
2. Zhang Q, *et al*. Nanodiamond-based platforms for drug delivery and bioimaging. Int J Nanomedicine,2012:7:1063–1077. doi:10.2147/IJN.S37348.
3. Krueger A. New carbon materials: Nanodiamond. Crit Rev Solid State Mater Sci,2009:34(1–2):1–19. doi:10.1080/10408430902831987.
4. Mochalin VN, *et al*. The properties and applications of nanodiamonds. Sci Adv,2015:1(6):1500439. doi:10.1126/sciadv.1500439.
5. Shenderova O, *et al*. Nanodiamond and its applications in biomedicine. J Biomed Mater Res A,2016:104(2):363–369. doi:10.1002/jbm.a.36369.
6. Mochalin VN, *et al*. Fluorescent nanodiamonds for biomedical imaging. ACS Nano,2015:9(7):7505–7519. doi:10.1021/acsnano.5b05718.
7. Krueger A, Lang D. Functionality of detonation nanodiamond particles. Part Part Syst Charact,2015:32(5):501–511. doi:10.1002/ppsc.201500027,
8. Zheng H, *et al*. Unveiling the complexity of nanodiamond structures. Proc Natl Acad Sci USA,2017:114(52):10889–E10897. doi:10.1073/pnas.1711924114.
9. Zheng H, *et al*. Structural evolution of nanodiamonds. Proc Natl Acad Sci USA,2023:120(12):2301981120. doi:10.1073/pnas.2301981120.
10. Wang N, Lin P-Y, Yang J-C, Gutmann JL, Chang H-C, Huang H-M, *et al*. Micro-CT evaluation of a nanodiamond irrigant for hard-tissue debris removal during sonic agitation. Int Endod J,2025:58:346–356. doi:10.1111/iej.14176.
11. Krueger A, *et al*. Nanodiamond scaffolds in regenerative medicine. Proc Natl Acad Sci USA,2017:114:10889–E10897. doi:10.1073/pnas.1711924114.
12. Hargreaves KM, Cohen S, editors. Grossman's Endodontic Practice. In: Endodontics. Elsevier, 2016. doi:10.1016/B978-0-32-343029-6.00002-7.